Recent progress in scanning probe microscopy at Argonne's CNM

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Scientific Thrust Area:

The static and dynamic properties of magnetic nanostructures and strongly correlated materials are of intense current interest in both basic and applied research. Argonne's Center for Nanoscale Materials has science thrusts in the spin dynamics of nanostructures as well as in the atomic-scale characterization of complex oxides and their emerging electronic and magnetic material properties. Significant progress has recently been achieved in both areas.

Research Achievements:

One important pre-condition for cross-sectional STM on complex-oxide heterostructures is that the substrate, single crystalline $SrTiO_3$, can be cleaved/fractured resulting in high quality surfaces. We have successfully achieved the following milestones (see Fig. 1):

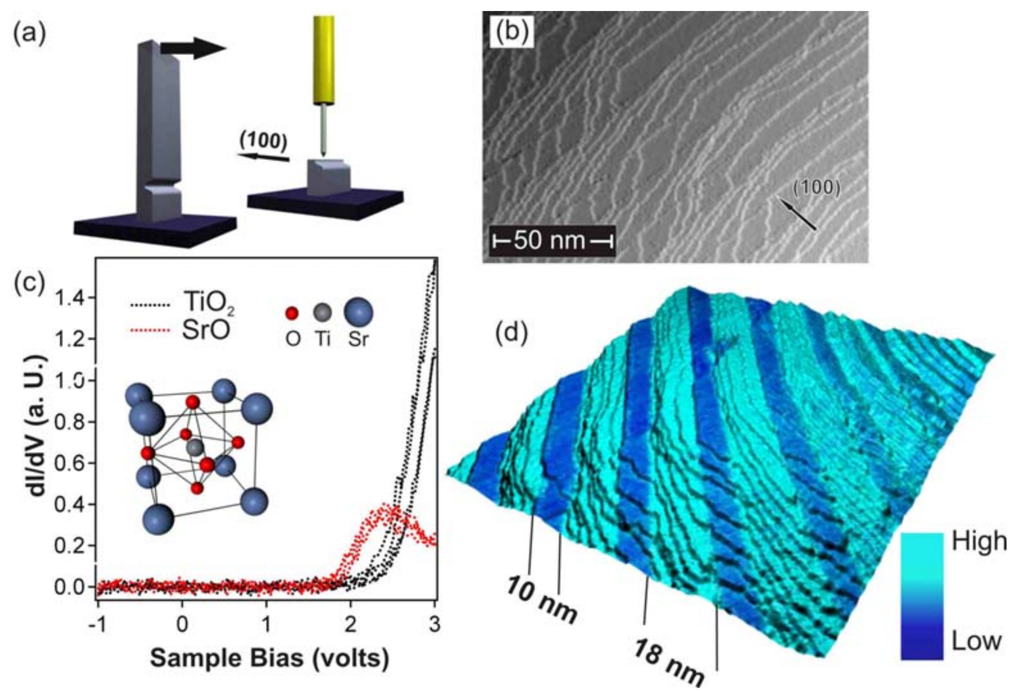

Figure 1(a): Schematic representation of the cleavage process of STO substrates. (b) Topography of the cleaved $SrTiO_3$(001) surface. (c) Tunneling spectra taken on TiO_2 and SrO terminated terraces revealing a strikingly different LDOS in the empty electronic states. (d) Rendered 3-dimensional representation of the surface topography shown in (b) color-coded with the simultaneously measured dI/dV conductance map.

(i) For the first time the cleavage/frature of $SrTiO_3$ has been investigated with the STM revealing large facets of (001) surfaces.

(ii) STM and STS measurements studying the correlation of structural and electronic properties by differential conductance mapping.

Also, we have performed temperature-dependent measurements of the Mn monolayer on W(110) which is known to exhibit a rather complex magnetic structure [1], i.e. a cycloidal antiferromagnetic spin spiral [see inset of Fig. 2(b)]. In this spin spiral in-plane and out-of-plane antiferromagnetic order alternate with a 6 nm period can be visualized because of their different electronic properties [Fig. 2(b)]. Our results suggest that the Néel temperature (long range magnetic order) depends on terrace width.

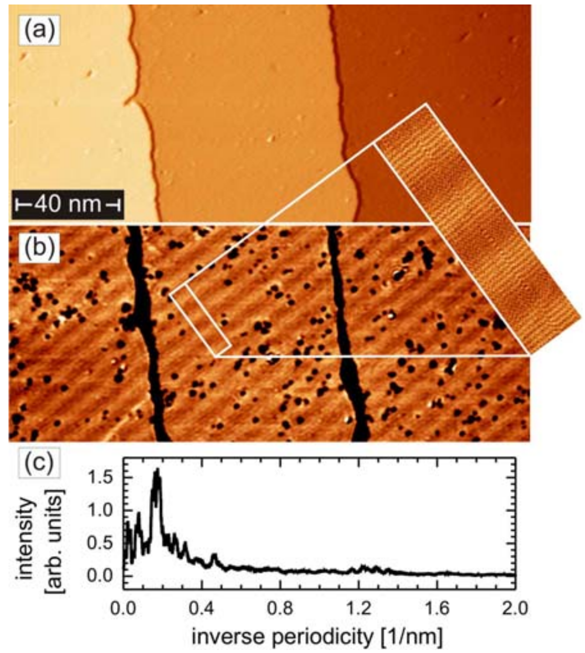

Figure 2. (a) Constant-current STM image of 0.95 AL Mn/W(110). The Mn monolayer is known to form a cycloidal antiferromagnetic spin spiral. (b) Differential conductance maps obtained with a magnetic Fe-coated probe tip. The large scale image shows a modulated intensity originating from spin-orbit coupling with in-plane and out-of-plane magnetized regions exhibiting slightly different spin-averaged electronic properties. The atomic-scale antiferromagnetic order becomes visible at higher resolution (inset). (c) Fourier-spectrum of line sections taken along the [1$\underline{1}$0] direction, i.e. perpendicular to the stripes in (b).

Future work:

The next step in our experiments on complex-oxide superlattices will be to reliably locate the edge of the sample. After this is accomplished we will investigate structural, electronic, and magnetic properties of the superlattices. Key questions will be:

(i) Can we distinguish the compounds based on their different structural electronic properties?

(ii) Does the interface exhibit extraordinary electronic properties?

(iii) How do the interfaces order on the atomic-scale?

In the case of antiferromagnetic nanostructures we will focus on the following questions:

(i) What is the relation between short- and long-range magnetic order?

(ii) How do single antiferromagnetic particles behave when thermally activated magnetization reversal processes kick in?

References:

[1] M. Bode et al., *Chiral magnetic order at surfaces driven by inversion asymmetry*, Nature 447, 190 (2007)